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CARDIAC

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# Radiation dose of cardiac CT—what is the evidence?

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**Abstract** Current evidence and most pertinent literature on the radiation dose of cardiac computed tomography (CT) for the noninvasive assessment of coronary artery disease are reviewed. The various means for adjusting CT protocols to lower the radiation to a level that is as low as reasonably achievable are discussed. It is shown that for the target population of cardiac CT, the direct visualization of the heart and coronary arteries outweighs the hypothetical risk of the investigation, provided that indications are prudent and the protocols appropriate.

**Keywords** Cardiac · Computed tomography · Radiation dose · Risk

The advent of multidetector row spiral computed tomography (CT) represents one of the most groundbreaking innovations in the field of diagnostic imaging in the past decades. The major achievements of current CT systems are their high temporal and high spatial resolution, combined with fast volume coverage. These together enable the robust noninvasive imaging of the heart and coronary arteries with an exceptional quality and accuracy [1–3].

Because the improved performance of cardiac CT is accompanied by its more widespread utilization, the number of imaging tests has increased in the past years. This holds true not only for cardiac CT but also for other cardiac imaging investigations involving radiation, such as diagnostic catheter angiography or nuclear medicine.

The downside of the increasing use of radiation-associated cardiac imaging tests is the increase in the collective radiation dose, which is of potential risk to the population. Thus, concerns about the utilization of CT and the associated increase in the collective radiation dose to the general population have abounded [4]. Recently, Brenner et al. [5] stated in his widely disseminated review that “although the risks for any one person are not large, the increasing exposure to radiation in the population may be a public health issue in the future.”

Thus, it is incumbent upon cardiac imagers utilizing X-rays to be aware of the radiation doses they apply and of the potential risk the imaging procedures impose on their patients [6]. The following article is intended to summarize some of the most pertinent issues related to radiation dose of cardiac CT.

## Why cardiac CT is radiation dose intensive

When considering the relatively small volume covered (i.e., only approximately 12–13 cm in the z-axis for adult hearts), cardiac CT must be considered an imaging test that is radiation dose intensive. The relatively high radiation dose values are the result of the relationship between image noise and resolution of the examination [7]. Image noise depends mainly on the number of X-ray photons reaching the detector. This number in turn depends on the object attenuation and tube voltage and is proportional to the slice width, tube current, and the amount of time necessary to acquire the projection data needed for image reconstruction [7]. In cardiac CT, the best possible temporal resolution is required to minimize artefacts resulting from cardiac motion. This goal is achieved by minimizing the number of projections used to reconstruct the image to those projections gathered in the shortest possible time window. A high temporal resolution requires fast gantry rotation times [8]. These, however, require a slower pitch to avoid discontinuities in the anatomic coverage of the heart. A slow pitch, in turn, yields a higher radiation dose. Thus, the high temporal and spatial resolution required for cardiac CT is obtained at the expense of an increase in radiation dose.

## Ways to reduce the radiation dose of cardiac CT

*Indications* One of the first steps in limiting the radiation burden to the population is to adhere to accepted indications for cardiac CT. The most important indication of cardiac CT is an adult patient with atypical chest pain having a low to intermediate pre-test probability of coronary artery disease, an uninterpretable ECG and/or is unable to exercise [9, 10]. Cardiac CT can then serve as a filter test, according to which the patient may or may not undergo further imaging work-up.

Another important indication of cardiac CT is the evaluation of suspected coronary anomalies where CT is considered the gold-standard imaging tool. Various other indications of cardiac CT have been investigated with great promise, such as the follow-up evaluation of aorto-coronary artery bypass grafts [11], and the evaluation of global and regional ventricular function [12, 13] and cardiac valves [14]. Other indications are currently under exhaustive investigation and extend cardiac CT to the assessment of myocardial perfusion [15] and viability [16].

Most importantly, CT coronary angiography should not be used as a screening tool [9, 10]. Various national and international radiology and cardiology societies have agreed not to recommend the use of CT coronary angiography in asymptomatic persons as a screening test (class III, level of evidence C) [10].

*Z-axis coverage* A relatively simple and effective way to reduce the radiation dose associated with cardiac CT is to limit the *z*-axis coverage to the minimum required. For example, it may not be necessary to examine the entire ascending aorta. In addition, the *z*-axis coverage can be effectively adjusted and eventually reduced using the calcium scoring images acquired before the contrast-enhanced CT coronary angiography examination.

*ECG synchronization* An important way to reduce the radiation dose to a value that is as low as reasonably achievable is to tailor the protocol parameters to the individual patient characteristics [17].

At irregular and/or higher heart rates, it is mandatory to use the spiral data acquisition technique with retrospective ECG gating. With this technique, data are acquired throughout the entire cardiac cycle, and images can be reconstructed in various phases of the cardiac cycle [18]. This may be particularly important when reconstructing data in systole, which often is required in patients having heart rates above 80 bpm [19]. The downside of the retrospective ECG-gating mode is the higher radiation dose because of the continuous X-ray exposure. On the other hand, the dose can be considerably lowered by using the technique of ECG-controlled tube current modulation (or ECG pulsing) [20]. This technique is characterized by a peak tube output during mid- to end-diastole and a reduction of tube output to 25% during other parts of the cardiac cycle. As mentioned above, CT coronary angiography data need to be reconstructed in systole particularly at higher heart rates [19]. Thus, the width of the ECG-controlled tube current modulation window should be adapted to the individual heart rate of the patient. It should be narrow at lower and wider at higher heart rates [21].

When the heart rate is regular and below a certain level (the level itself depends on the specific CT system being used), the dose-saving technique of prospective ECG triggering (or step-and-shoot mode) can be employed [22]. Prospective ECG triggering is characterized by turning on the X-ray tube only at a predefined time point in the cardiac cycle (usually in mid-diastole) while keeping the patient table immobile. This technique is inherently associated with a low X-ray exposure time and thus with a low radiation dose to the patient [23–25]. The downside of this technique is that it cannot be applied in patients with higher or irregular heart rates, conditions that are unfortunately relatively common in the target population of cardiac CT. Finally, the inherent limitation of the low-dose protocol is that functional information (i.e., the assessment of ventricular or valvular function) cannot be obtained.

*Tube voltage* A useful and perhaps underestimated way to reduce the radiation dose involves lowering the tube voltage, because the radiation dose varies with the square of the tube voltage [26]. On the other hand, a reduced tube voltage must be always weighed against an increase in image noise [24, 27]. Thus, use of a low tube-voltage protocol is recommended only in normal weight or underweight patients, in order to maintain a diagnostic contrast-to-noise ratio [26].

When utilizing all these factors affecting and reducing the radiation dose, retrospectively ECG-gated CT coronary angiography protocols with 64-slice CT machines are associated with effective doses of 10–12 mSv [28] compared with 7–9 mSv for dual-source CT [29], with both techniques involving the use of ECG-controlled tube current modulation. When reducing the tube voltage to 100 kV, retrospectively ECG-gated CT coronary angiography can be lowered to approximately 5–7 mSv [26]. Finally, use of the prospective ECG-triggering technique further lowers the effective dose to 1–3 mSv [23–25]. It should be noted that the latter effective dose values are below those from standard chest and abdomen CT examinations (even in protocols including only one phase), and also are below the levels of natural background radiation an individual is exposed to throughout each year of his or her life.

## Special protocols with higher doses

Particular attention must be paid to the use of chest-pain or so-called triple-rule-out protocols where the entire chest is included [30–32]. These protocols are associated with an increase in radiation exposure to the patient when compared to a standard cardiac CT examination. A recent study has shown that radiation doses for a chest-pain CT including the entire chest are associated with effective doses ranging from 14 to 22 mSv [33]. Certainly, the increase in potential harm associated with such CT protocols needs to be individually weighed against the potential benefits of the imaging test [34]. Often, the use of a triple-rule-out CT reduces the number of other, invasive, diagnostic procedures that may also involve radiation and contrast-media exposure.

## Radiation dose—what is the risk?

The biological effects of ionizing radiation such as X-rays have been studied extensively. Nevertheless, they are still the subject of controversy [35]. Effective doses above 100 mSv have been shown to be linked to deleterious consequences such as the induction of cancer. The biological effects of lower levels of radiation as are common in diagnostic X-ray imaging, on the other hand, are much less clear.

One of the main difficulties in assessing the radiation risks in the low-dose range of diagnostic imaging is a statistical one. In order to quantify the risk with a reasonable statistical power, epidemiological studies with life-time follow-up in millions of individuals exposed to radiation would be required [36]. Although this is not feasible, it is today generally believed that no level of radiation is without some risk. To estimate the practically immeasurable risk from low levels of radiation, various mathematical models have been suggested to extrapolate the dose-risk relationship based on highly exposed populations [37]. The hypothesis most commonly used assumes a linear relationship between radiation and risk for low-level exposures; this hypothesis is thus called the linear no-threshold hypothesis.

## Coronary CT—the alternative investigation

CT for the noninvasive visualization of the coronary arteries is not usually an alternative to *no* imaging test, but rather a noninvasive alternative for cardiac catheterization. Thus—assuming an appropriate and prudent indication for cardiac CT—the risk of missing the diagnosis of coronary artery disease must be higher than the hypothetical risk of the test. Furthermore, when discussing the potential risk of cardiac CT, it is also imperative to include in the considerations the risk of the alternative procedure [37]. According to the literature [38], purely diagnostic catheter coronary angiography is associated with effective radiation doses between 2.3 and 22.7 mSv, with some purely diagnostic catheter angiography studies exceeding 100 mSv [29]. In addition, cardiac catheter carries a procedure-related risk of mortality of 0.11% and a 1.3% risk of major complications [37]. Whereas the radiation dose of cardiac CT approaches the lower levels of those reported for diagnostic cardiac catheter, the procedure-related risks are virtually absent with the noninvasive investigation.

## Conclusion

Cardiac CT is undergoing tremendous developments leading to an increasingly robust and accurate imaging technique that is available in more and more centers worldwide. Each new generation of scanners improves the accuracy of noninvasive coronary artery imaging. Along with the development of new CT scanners, new indications are studied, developed, and eventually enter our daily clinical routine. The radiation dose of CT protocols for cardiac imaging continues to decrease and currently approaches the lower range of values from invasive investigations. Unfortunately, much of what is written and disseminated about radiation dose is simply done for political reasons with the aim to achieving the advantage in turf battle situations. Thus, it is even more important to strictly adhere to scientific evidence when discussing this issue. Awareness of the basic principles of the risk induced by the exposure of our patients to ionizing radiation is mandatory for each cardiac imager. The risk of diagnostic imaging with CT is purely hypothetical, can only be extrapolated from higher dose exposures, and is most probably extremely small. The enormous advantage of this *non-invasive* tool enabling the *direct* visualization of coronary arteries outweighs the hypothetical risk of the investigation, provided that indications are prudent and the protocols appropriate.

## References


1. Scheffel H, Alkadhi H, Plass A et al (2006) Accuracy of dual-source CT coronary angiography: first experience in a high pre-test probability population without heart rate control. Eur Radiol 16:2739–2747
2. Ropers U, Ropers D, Pflederer T et al (2007) Influence of heart rate on the diagnostic accuracy of dual-source computed tomography coronary angiography. J Am Coll Cardiol 50:2393–2398
3. Johnson TR, Nikolaou K, Wintersperger BJ et al (2006) Dual-source CT cardiac imaging: initial experience. Eur Radiol 16:1409–1415
4. Dixon AK, Dendy P (1998) Spiral CT: how much does radiation dose matter? Lancet 352:1082–1083
5. Brenner DJ, Hall EJ (2007) Computed tomography-an increasing source of radiation exposure. N Engl J Med 357:2277–2284
6. Achenbach S, Anders K, Kalender WA (2008) Dual-source cardiac computed tomography: image quality and dose considerations. Eur Radiol 18:1188–1198
7. Primak AN, McCollough CH, Bruesewitz MR et al (2006) Relationship between noise, dose, and pitch in cardiac multi-detector row CT. Radiographics 26:1785–1794
8. Flohr TG, McCollough CH, Bruder H et al (2006) First performance evaluation of a dual-source CT (DSCT) system. Eur Radiol 16:256–268
9. Hendel RC, Patel MR, Kramer CM et al (2006) ACCF/ACR/SCCT/SCMR/ASNC/NASCI/SCAI/SIR 2006 appropriateness criteria for cardiac computed tomography and cardiac magnetic resonance imaging: a report of the American College of Cardiology Foundation Quality Strategic Directions Committee Appropriateness Criteria Working Group, American College of Radiology, Society of Cardiovascular Computed Tomography, Society for Cardiovascular Magnetic Resonance, American Society of Nuclear Cardiology, North American Society for Cardiac Imaging, Society for Cardiovascular Angiography and Interventions, and Society of Interventional Radiology. J Am Coll Cardiol 48:1475–1497
10. Budoff MJ, Achenbach S, Blumenthal RS et al (2006) Assessment of coronary artery disease by cardiac computed tomography: a scientific statement from the American Heart Association Committee on Cardiovascular Imaging and Intervention, Council on Cardiovascular Radiology and Intervention, and Committee on Cardiac Imaging, Council on Clinical Cardiology. Circulation 114:1761–1791
11. Marano R, Liguori C, Rinaldi P et al (2007) Coronary artery bypass grafts and MDCT imaging: what to know and what to look for. Eur Radiol 17:3166–3178
12. Puesken M, Fischbach R, Wenker M et al (2008) Global left-ventricular function assessment using dual-source multidetector CT: effect of improved temporal resolution on ventricular volume measurement. Eur Radiol 18:2087–2094
13. Fischbach R, Juergens KU, Ozgun M et al (2007) Assessment of regional left ventricular function with multidetector-row computed tomography versus magnetic resonance imaging. Eur Radiol 17:1009–1017
14. Alkadhi H, Desbiolles L, Husmann L et al (2007) Aortic regurgitation: assessment with 64-section CT. Radiology 245:111–121
15. Ruzsics B, Lee H, Zwerner PL et al (2008) Dual-energy CT of the heart for diagnosing coronary artery stenosis and myocardial ischemia-initial experience. Eur Radiol 18:2414–2424
16. Mahnken AH, Muhlenbruch G, Gunther RW et al (2007) Cardiac CT: coronary arteries and beyond. Eur Radiol 17:994–1008
17. Alkadhi H, Stolzmann P, Scheffel H et al (2008) Radiation dose of cardiac dual-source CT: the effect of tailoring the protocol to patient-specific parameters. Eur J Radiol 68:385–391
18. Leschka S, Scheffel H, Desbiolles L et al (2007) Image quality and reconstruction intervals of dual-source CT coronary angiography: recommendations for ECG pulsing windowing. Invest Radiol 42:543–549
19. Leschka S, Husmann L, Desbiolles LM et al (2006) Optimal image reconstruction intervals for non-invasive coronary angiography with 64-slice CT. Eur Radiol 16:1964–1972
20. Jakobs TF, Becker CR, Ohnesorge B et al (2002) Multislice helical CT of the heart with retrospective ECG gating: reduction of radiation exposure by ECG-controlled tube current modulation. Eur Radiol 12:1081–1086
21. Leschka S, Scheffel H, Desbiolles L et al (2007) Image quality and reconstruction intervals of dual-source CT coronary angiography: recommendations for ECG-pulsing windowing. Invest Radiol 42:543–549
22. Hsieh J, Londt J, Vass M et al (2006) Step-and-shoot data acquisition and reconstruction for cardiac x-ray computed tomography. Med Phys 33:4236–4248
23. Scheffel H, Alkadhi H, Leschka S et al (2008) Low-dose CT coronary angiography in the step-and-shoot mode: diagnostic performance. Heart 94:1132–1137
24. Stolzmann P, Leschka S, Scheffel H et al (2008) Dual-source CT in step-and-shoot mode: noninvasive coronary angiography with low radiation dose. Radiology 249:71–80
25. Stolzmann P, Scheffel H, Leschka S et al (2008) Influence of calcifications on diagnostic accuracy of coronary CT angiography using prospective ECG triggering. AJR Am J Roentgenol 191:1684–1689
26. Leschka S, Stolzmann P, Schmid FT et al (2008) Low kilovoltage cardiac dual-source CT: attenuation, noise, and radiation dose. Eur Radiol 18:1809–1817
27. Huda W, Scalzetti EM, Levin G (2000) Technique factors and image quality as functions of patient weight at abdominal CT. Radiology 217:430–435
28. Hausleiter J, Meyer T, Hadamitzky M et al (2006) Radiation dose estimates from cardiac multislice computed tomography in daily practice: impact of different scanning protocols on effective dose estimates. Circulation 113:1305–1310
29. Stolzmann P, Scheffel H, Schertler T et al (2008) Radiation dose estimates in dual-source computed tomography coronary angiography. Eur Radiol 18:592–599
30. Schertler T, Scheffel H, Frauenfelder T et al (2007) Dual-source computed tomography in patients with acute chest pain: feasibility and image quality. Eur Radiol 17:3179–3188
31. Johnson TR, Nikolaou K, Becker A et al (2008) Dual-source CT for chest pain assessment. Eur Radiol 18:773–780
32. Frauenfelder T, Appenzeller P, Karlo C et al (2008) Triple rule-out CT in the emergency department: protocols and spectrum of imaging findings. Eur Radiol. doi:10.1007/s00330-008-1231-3

33. Ketelsen D, Luetkhoff MH, Thomas C et al (2008) Estimation of the radiation exposure of a chest pain protocol with ECG-gating in dual-source computed tomography. Eur Radiol. doi:10.1007/s00330-008-1109-4
34. Stillman AE, Oudkerk M, Ackerman M et al (2007) Use of multidetector computed tomography for the assessment of acute chest pain: a consensus statement of the North American Society of Cardiac Imaging and the European Society of Cardiac Radiology. Eur Radiol 17:2196–2207
35. Verdun FR, Bochud F, Gundinchet F et al (2008) Quality initiatives* radiation risk: what you should know to tell your patient. Radiographics 28:1807–1816
36. Brenner DJ, Doll R, Goodhead DT et al (2003) Cancer risks attributable to low doses of ionizing radiation: assessing what we really know. Proc Natl Acad Sci USA 100:13761–13766
37. Zanzonico P, Rothenberg LN, Strauss HW (2006) Radiation exposure of computed tomography and direct intracoronary angiography: risk has its reward. J Am Coll Cardiol 47:1846–1849
38. Einstein AJ, Moser KW, Thompson RC et al (2007) Radiation dose to patients from cardiac diagnostic imaging. Circulation 116:1290–1305